

SCIENCE FOR GLASS PRODUCTION

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FORMATION FEATURES OF THIN FLOAT GLASS AND PROSPECTS FOR THIS TECHNOLOGY (A REVIEW)

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THE Principal methods for producing thin float glass are identified based on an analysis of patent information. Brief descriptions of patented methods are given. The problems of formation of thin float glass and ways of solving them are considered. Promising directions in the production of thin float glass are described.

A method for molding a glass band on a metal melt was introduced into world practice in the 1960s. Initially, the sheet-glass thickness was limited to 4 – 6 mm, and the production-line output did not exceed 300 ton/day.

Since that time the method has been improved substantially. This has made it possible to produce high-quality polished glass of different grades, including necked glass. Contemporary production lines manufacture glass 1.8 to 20.0 mm thick, and the output has increased to 1000 ton per day.

This technology consists, in essence, in feeding fluid glass onto the surface of melted metal contained in a tank. The fluid glass spreads over the metal-melt surface to the extent of the equilibrium thickness, gradually cools to the point of solidification, and is removed from the melting tank to an annealing furnace by the pulling forces of a roller conveyor.

Free spreading of liquid glass over melted metal to the equilibrium thickness complies with the general laws governing the behavior of mutually non-mixing and non-wetting liquids of different densities. It depends on the density of the liquids and their surface tension at the phase boundary.

The equilibrium glass thickness in the industrial float process (formation of soda-lime glass on a tin melt) is around 7 mm.

In production of thin float glass, the glass band, after spreading, is subjected to additional treatment to impart the required thickness to it.

The patent literature describes numerous techniques for producing thin glass using the float technology. These methods can be divided into four groups depending on the glass necking principle:

1) modification of the parameters that decrease the equilibrium thickness of the glass;

2) the effect of external compressive forces (compression) on the surface of the glass band in the viscoplastic state;

3) the effect of longitudinal tensile forces on the glass band;

4) the effect of longitudinal-lateral tensile forces on the glass band.

An example of modification of the parameters that affect the equilibrium thickness is introduction of elements of group III, IV, V, or VI of the Periodic System into the tin melt, which modifies the surface tension on the tin-atmosphere and tin-glass phase boundaries and makes it possible to obtain equilibrium glass down to 4 mm thick (France patent No. 1499470).

Some methods entail using silver as the melted metal; in this case the band spreads to about 1 mm thick (Gr. Britain patent No. 989413).

Other patents describe supplying a liquid (a fourth phase) whose surface-tension coefficient is below that of glass to the glass-band edges (Gr. Britain patent No. 1109392, France patent No. 1370772). This also modifies the surface tension at the phase boundary, which under certain conditions allows a decrease in the equilibrium thickness of the glass to 6 mm (Fig. 1).

Among the second group of patents, based on the effect of external forces compressing both the upper and lower surfaces of the floating band, the following methods can be cited.

One method entails the development of excess hydrostatic pressure above the glass band in the molding zone by feeding an inert gas into the cavity above that zone (U.S. patents Nos. 3432283 and 3467650). In this case the band ex-

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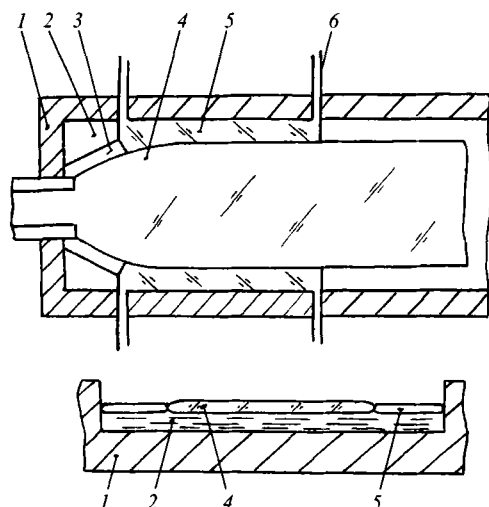


Fig. 1. Decreasing the equilibrium thickness of glass by feeding additional liquid to the glass-band edges: 1) melt tank; 2) tin melt; 3) restricters; 4) glass band; 5) additional liquid; 6) feed of additional liquid.

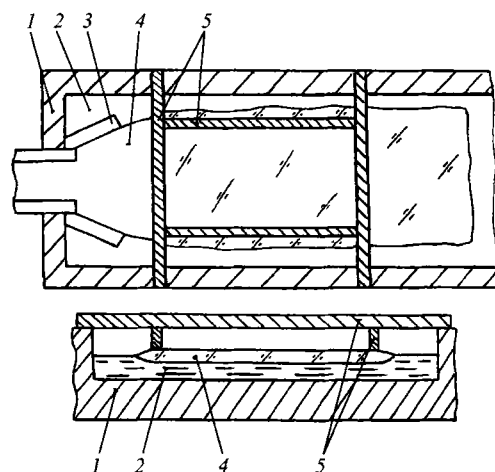


Fig. 2. Thinning the glass band by developing excess hydrostatic pressure by feeding an inert gas into a chamber: 1) melt tank; 2) tin melt; 3) restricters; 4) glass band; 5) walls enclosing the chamber into which the gas is fed.

periences two-sided compression and is gradually deformed along the entire length of this area, with the band thickness being reduced below the equilibrium level (Fig. 2). The development of excess hydrostatic pressure can also be accomplished by feeding melted metal onto a band of equilibrium thickness (Fig. 3), and band necking occurs under the weight of that metal (France patent No. 1408754).

Compression of the glass surface can also be accomplished using rotating rollers made of a material not wettable by liquid glass (Fig. 4), which are immersed in the band surface at a site where the band is in a viscoplastic state (U.S. patent No. 3486873, France patents Nos. 1336367 and 1424557).

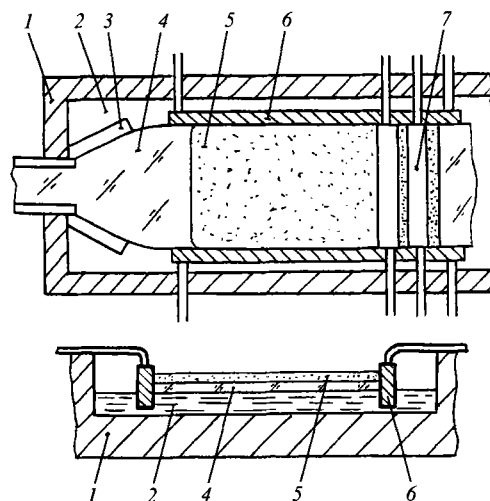


Fig. 3. Thinning the glass band by developing pressure using the weight of melted metal: 1) melt tank; 2) tin melt; 3) restricters; 4) glass band; 5) melted metal; 6) enclosing walls; 7) rollers separating the melted metal from the upper surface of the glass band.

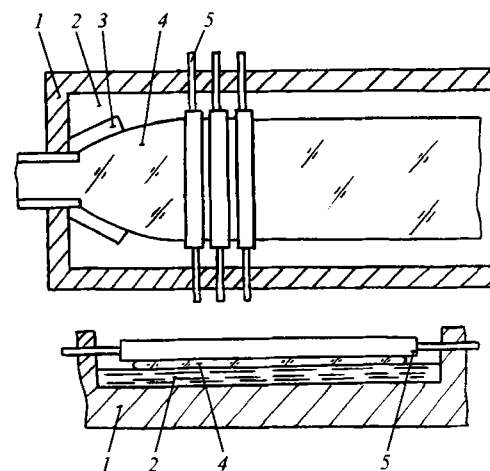


Fig. 4. Thinning the glass band by the pressure of rotating rollers: 1) melt tank; 2) tin melt; 3) restricters; 4) glass band; 5) rotating rollers.

The next group of methods entails longitudinal stretching of the band after it reaches the equilibrium thickness (Fig. 5), known as the direct-stretching method (France patent No. 1358677, U.S. patents Nos. 3468651 and 3737295). Direct stretching is performed by the pulling forces of roller-conveyor rollers and makes it possible to obtain glass down to 4.0 – 4.5 mm thick. In such stretching the glass band narrows significantly.

It should be noted that the methods described in the first, second, and third groups have not been pursued and are not currently implemented in float-glass production.

Finally, the fourth group of methods for float-glass necking is based on longitudinal-lateral extension of the band (U.S. patents Nos. 4349642 and 4354866, Gr. Britain patents Nos. 1010913 and 1313743; USSR patents Nos. 775997,

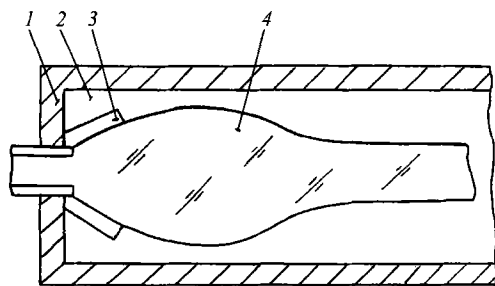


Fig. 5. Thinning the glass band by direct stretching: 1) melt tank; 2) tin melt; 3) restricters; 4) glass band.

367685, 485079, etc.). These methods are more widely represented in the patent literature and, unlike the methods listed above, are used on industrial float lines. In this connection they merit closer consideration.

The first necking method developed that makes it possible to obtain a relatively wide glass band (down to 3 mm thick) is the "cold bar" method (Fig. 6). According to this method, after the glass band spreads to a plane-parallel layer of equilibrium thickness, it is chilled and then subjected to repeated heating to the viscoplastic state and necked under the effect of linear tensile forces while its edges are maintained by edge-maintaining devices.

The intermediate chilling of the band creates a barrier ("a cold bar") that impedes the transfer of linear tensile forces to the head area of the tank, where the glass band spreads, forming a pool, which reduces the intensity of its narrowing.

Nevertheless, this method narrows the glass band significantly, which is its main disadvantage.

Therefore, it was proposed that intermediate chilling of the glass be eliminated and lateral tensile forces be applied to the band edges immediately after the glass-melt spreading. This aim is accomplished by using groups of edge-stretching machines with adjustable speeds that are symmetrically positioned at an angle to the longitudinal axis of the glass band (Fig. 7).

The implementation of this method of glass formation showed the possibility of producing a wider glass band of thickness less than 3 mm. The production rate decreased (for an equal glass thickness and equal glass-melt output). The power consumption was reduced, since the secondary heating of the glass band was eliminated. This produced a substantial economic gain. Moreover, in contrast to the "cold bar" method, this method made it possible to change over to producing thin glass by changing the speeds of the edge-stretching machines, their angles of turn, and the production rate without decreasing the efficiency of the glassmaking furnace, which is a more favorable regime of furnace operation.

Thus, production of thin float glass using longitudinal-lateral stretching has undeniable advantages over other possible methods. This method is currently employed on all float-glass lines.

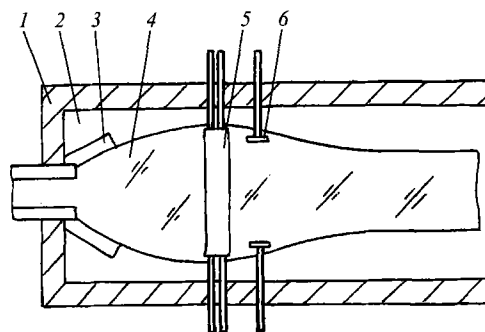


Fig. 6. Thinning the glass band by the "cold bar" method: 1) melt tank; 2) tin melt; 3) restricters; 4) glass band; 5) cooler; 6) edge-maintaining mechanisms.

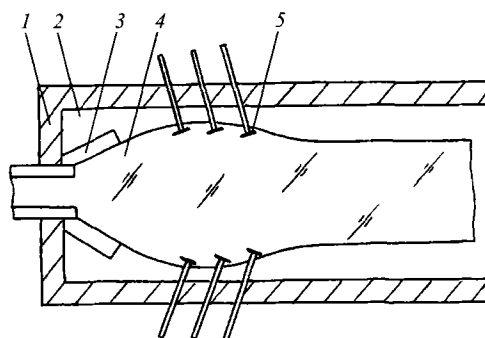


Fig. 7. Thinning the glass band by longitudinal-lateral stretching: 1) melt tank; 2) tin melt; 3) restricters; 4) glass band; 5) edge-stretching mechanisms.

The increased efficiency of float lines resulted in increased production rates, especially for thin glass grades. For instance, glass 2 mm thick is produced at a rate of 1000 – 1200 m/h. A glass band moving at a high speed entrains melted tin, and therefore, intense tin currents arise in the melt tank. The tin is entrained by the glass band from the hotter (head) zone of the tank to the cooler (tail) zone. As the result, first, the tail-zone temperature increases, and second, opposite currents arise, since the cooled tin from the tail zone, moving along the tank bottom and edges, migrates into the middle and even the head tank zone. Therefore, substantial temperature differences arise in the tin melt (primarily across the tank width). This is especially unfavorable for the tank zone in which intense necking of glass takes place. If the temperature field is nonuniform here, different portions of the glass band acquire different levels of viscosity, and under the effect of tensile forces they are deformed with different intensity, which results in nonuniform thickness and degrades the optical parameters of the glass band.

Consequently, the problem of production of thin float glass is closely related to the problem of tin flow control. This problem is discussed extensively in the literature, and several methods are suggested to suppress undesirable migrations of the tin melt.

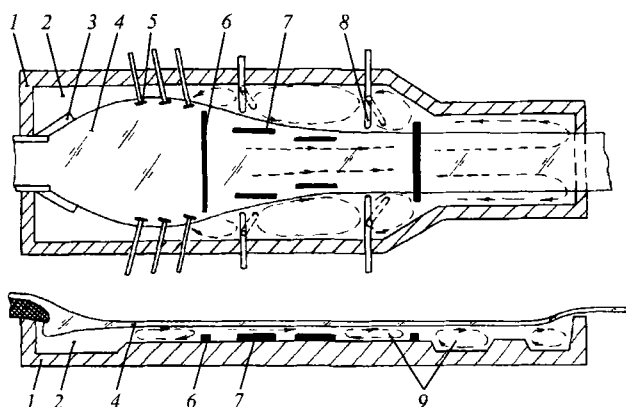


Fig. 8. Methods for restricting the tin flows: 1) melt tank; 2) tin melt; 3) restricters; 4) glass band; 5) edge-stretching mechanisms; 6) lateral barriers; 7) longitudinal barriers; 8) mobile side barriers; 9) indentations in the tank bottom; the dashed lines indicate tin currents and directions of tin migration in the tank.

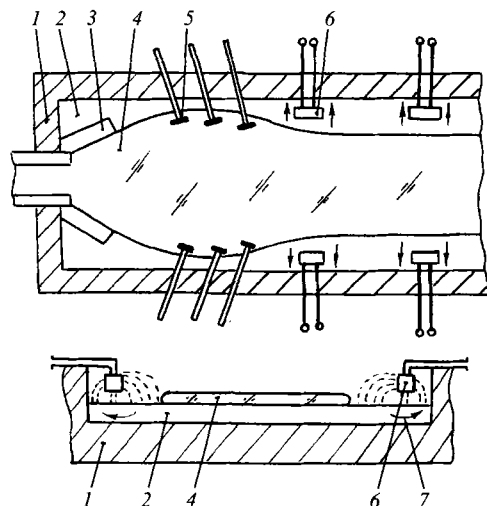


Fig. 9. Controlling the tin flows by linear electromagnetic motors: 1) melt tank; 2) tin melt; 3) restricters; 4) glass band; 5) edge-stretching mechanisms; 6) linear electromagnetic motors; 7) excited tin flows.

One efficient method consists in installing lateral and longitudinal bottom barriers (Fig. 8) that protrude from the tank bottom (Gr. Britain patent No. 1452625, U.S. patents Nos. 3930828 and 4099952). Lateral bottom barriers attenuate both direct (from hot to cold zones) and reverse tin flows.

Longitudinal barriers prevent the cooled tin located near the tank side walls from penetrating beneath the glass band. As a consequence, the temperature of the tin under the band becomes more uniform. These barriers are usually placed in the zone of intense necking, since penetration of cooled tin into that zone is especially undesirable.

For the barriers to be effective, it is important to correctly select their position and the angle of the working plane of the barrier with respect to the tin currents. The required site for barrier installation differs for different technological

regimes. Therefore, mobile barriers have been designed (see Fig. 8, France patent No. 2471954). The most common in float technology are mobile side barriers known as "flags" (dissectors).

In addition to barriers, tin flows are regulated by special profiling of the bottom of the melt tank (see Fig. 8), i.e., by modification of the bottom profile at various sites (U.S. patent No. 4131446).

One of the most radical methods for preventing inhomogeneity of the tin temperature is the installation of a "false bottom" in the tank, where a channel is made beneath the main bottom, and the tin moves along this channel from the tail zones to the head zones and penetrates under the glass band in the pool area, not touching the areas of intense necking (Gr. Britain patent No. 1314537, U.S. patent No. 3393061, USSR patent No. 307560).

Other methods for regulating the heat and mass transfer of tin flows are described in the literature. One of them consists in using mechanical mixers and linear electromagnetic motors (Fig. 9) to create desirable tin flows and suppress undesirable ones (USSR patents Nos. 699788 and 776477, France patent No. 2094030, Gr. Britain patent No. 15442824).

In addition, an alternative approach is used: instead of regulating the mechanical migration of the tin, the temperature of the flows is controlled. For this purpose, heaters or coolers immersed in the tin are used (Gr. Britain patent No. 1452625, U.S. patent No. 3622299). Their use also makes it possible to eliminate unfavorable temperature gradients in the molding zone.

In spite of the substantial variety of methods for controlling tin flows, a general tendency can be observed, namely, tin flows in the melt tank are decelerated and temperature gradients across the width and depth of the tin layer in each cross section of the tank are reduced.

The application of above-described methods has resulted in high quality for the produced glass.

Highly efficient float lines currently produce high-quality glass down to 1.8 – 2.0 mm thick. The float technology allows production of even thinner glass (superthin grades). However, this calls for the use of special techniques.

The forecast of further evolution of thin-glass production shows good prospects for energy-saving float technologies. The traditional approach includes heating in the head and middle zones of the float tank and intense cooling in the tail zone. The new approach entails heat-exchange regulation in the float tank that leads to less intense heating and less intense cooling, while the total thermal balance is preserved.

For this purpose, new devices for more precise control of the thermal conditions in the melt tank are being developed, such as special heaters installed in observation openings in the tank, coolers with adjustable heat removal, etc.

Furthermore, the float process in general shows a tendency toward a reduction in the number and protraction of the operations involved in rearrangement of the technological equipment (the protraction of the process readjustment)

and, in addition, unification of the positioning of the technological equipment.

The purpose of these improvements is to avoid manual relocation of the equipment units (edge-stretching mechanisms, coolers, limiters, etc.), which, in turn, contributes to automation of the float process, including the stages of production of a certain grade of glass and the conversion from one grade of glass to another.

The trend to saving tin and more rational use of the melting tank is manifested in the persistent tendency to increase the ratio between the glass-band width and the pool width. Improvement of the stretching devices and rational use of

heating and cooling can make it possible to manufacture a glass band whose width approaches the pool width.

Progress in the described research areas, i.e., strict heat-exchange control, unification of the positioning of the equipment units, and making the glass band wider, should increase substantially the efficiency and profitability of the float process. In this case the demand for thin glass in the market (multiple window panes, hardened glass, triplex glass, etc.) will be fully satisfied.

The Saratov Institute of Glass carries out active research in the field of improving the technologies for thin-glass production and currently possesses a number of developments that may be of interest to float-glass manufacturers.